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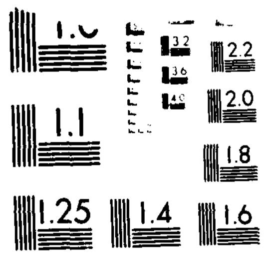

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EISCAT ELECTRON DENSITY STUDIES

C.J. Burns and J.K. Hargreaves
Department of Environmental Science,
University of Lancaster,
Lancaster LA1 4YQ,
England.

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ABSTRACT

The study of F-region electron density irregularities has continued and further runs of the Special Program have been scheduled to coincide with overpasses of the HILAT satellite. Programming improvements have led to more effective analysis of the data from both EISCAT and HILAT observations. Major variations in electron content are shown to be related to well defined enhancements of electron density. Typical periods range between 35 and 200 seconds, implying spatial structures of 12 to 70 km. These variations would have significant effects on transionospheric radio propagation. Preliminary comparisons have been made between EISCAT and HILAT measurements of total electron content. A significant difference between the measurements is observed, the HILAT observations being 2.2 times larger than those derived from EISCAT. The HILAT measurements from December 1985 appear to be too large. A brief description is given of the first run of the Special Program on the VHF radar.

CONTENTS

1. Introduction

Since August 1981, when the European Incoherent Scatter Radar (EISCAT) first started operating, several runs of a Special Program (SP103) have been made using the UHF radar. With support from AFOSR, development of the Special Program began in May 1981. Its aim was to observe the irregular structure of the high-latitude ionospheric F-region down to scale sizes of a few kilometers. A total of 15 runs of SP103 have been made up to the end of this reporting period, the two most recent being with the new VHF radar. Since December 1983 most experiments have been planned to coincide with overpasses of the HILAT satellite. This has enabled comparisons to be made of measurements in the F-region by two different techniques.

This report summarises progress from the previous grant period of May 1981 - January 1985 and then describes the work done in the present half-time project, August 17 1986 - August 17 1987. Two papers are included as appendices. Appendix 3 summarizes the software used in the project.

2. The Project from May 1981 to January 1985

Three previous reports describe the work done during this period:

1 May 1981 - 30 April 1982	AFOSR-81-0049	J.K. Hargreaves & S.C. Kirkwood
1 May 1982 - 30 April 1983	AFOSR-83-0054	S.C. Kirkwood & J.K. Hargreaves
15 Oct 1983 - 29 Jan. 1985	AFOSR-83-0371	J.K. Hargreaves & C.J. Burns

Work during the first year was mainly concerned with determining the feasibility of EISCAT observations for likely magnitudes, scale sizes and drift speeds of irregularities. It was established that under favourable conditions of high electron density and low drift speeds, irregularities with typical amplitudes down to scale-sizes of 5 km would be detectable. The first version of EISCAT Special Program SP103 was then written, and this was first run in December 1981. At that time the EISCAT UHF radar was still undergoing commissioning problems. No appreciable irregularities were detected during this run.

During the second year software was developed to analyse the data from the first and future experiments. It was confirmed that no ionospheric fine structures had been detected in December 1981. Conditions had been magnetically quiet during the run. The second experiment was run in June 1982 under more active conditions but near noon. No structure was detected during this run either. Although neither of the first two experiments were successful in detecting ionospheric structures they did serve as trial runs and allowed development of the methods of analysis. They also revealed several shortcomings in the EISCAT system which have since been corrected. Two further runs of the experiment were made on 29/30 November 1982. The experiment had been improved by extending the scanning arc and including an E-region power profile. It was run under conditions more conducive to irregularities - on a magnetically disturbed day near midnight. Two consecutive runs were made and both succeeded in detecting irregularities.

The EISCAT facility was closed for major repairs between January and September of 1983. As a consequence SP103 was not run again until December 1983. By this time it was possible to coordinate runs with simultaneous overpasses of the HILAT satellite. The first coincident pass was obtained during the December 1983 experiment. However the tape of HILAT data did not arrive at Lancaster until late 1984, too late for any work to be done during that reporting period. Further runs of SP103 were made in February 1984 and December 1984. The runs made on 15 and 16 December 1984 were both associated with HILAT passes. During this third reporting period, work continued on the analysis of data from November 29/30. Comparisons were shown between observed range time behaviour and plasma drift determined from tristatic reception (Hargreaves et al., 1985a). Spectral analysis also revealed wavelike variations in electron density of spatial length 15 km, assuming a drift speed of 250 m/s. A considerable improvement in networking facilities between UK computers during 1983 made our access to the EISCAT data much easier than before.

3. Description of UHF and VHF Special Programs

The UHF Special Program SP103 was described in the second and third year reports and details are given in Table 1. A variant of this experiment was run on February 19 1987. This consisted of 11 stationary observations at 5 positions - looking up the field line or at the extremities of the cross pattern. In all other respects the experiment was the same as previous versions of SP103.

Since the last reporting period the VHF radar has started operating (1986) and full operation is expected before the end of 1987. Details of the system are given in Table 2. A first attempt at using a new

Table 1 : EISCAT UHF system and experiment SP103

Locations

	Geographic	Corrected geomagnetic	L
Tromsø (Transmitter, receiver)	69.6°N, 19.2°E	66.6°N, 104.9°E	6.17
Kiruna (Receiver)	67.9°N, 20.4°E	64.9°N, 104.2°E	5.38
Sodankylä (Receiver)	67.4°N, 26.7°E	63.9°N, 108.5°E	5.03

Antennas

Diameter : 32 m
Gain : 48 dB
Half-power beamwidth : 0.6° ≡ 3 km at 300 km range
Steerability : elevation 10°-90°
: azimuth 270°
Maximum slewing rate 80°/minute.

Transmitter and receivers

Frequency : 933.5 ± 2.5 MHz (8 frequencies in 0.5 MHz steps)
Peak power : Up to 2 MW (∼1 MW used)
Maximum duty cycle : 12.5
Noise temperature : nominally 145°K(Tromsø) .45°K(Remotes)
Pulse repitition rate : 0-1000 Hz
Pulse length : 10 μs-10 ms

Experiment SP103

Pulse sequence repitition rate : 125 Hz or 117 Hz.
Pulse lengths : 50 μs (power profile), 250 μs (tristatic), 5 x 20 μs (multipulse)
Integration time : 4 s.
One experiment comprises 10 or 11 sections of 512 s each
One scan covers 128 km at 300 km range
Experiment sequence : St, S→N, N→S, S→N, N→S, St, E→W, W→E, E→W, W→E, St
(where St ≡ field-aligned)
Range gate : 37.5 km
Ranges sampled : starting at 184 km to 671.5 km (14 gates) or to 746.5 km (16 gates).
Remote stations receive from 300 km range.
ACF's computed at 25 points with 10 μs lag.

Table 2 Details of EISCAT VHF System

Location

	Geographic	Corrected Geomagnetic	L
Tromsø (Transmitter and receiver)	69.6°N, 19.2°E	66.6°N, 104.9°E	6.17

Antenna

Parabolic cylinder of 4 independently moveable panels
Each panel : 40 m high, 30 m wide
Total area : 40 x 120 m (effective 3250 m^2)
Beamwidth : 1.7° x 0.6°
Steerability : in plane 0.5° west of north
Maximum speed : 5°/min.
Off-axis phase steerability : 21.3° in steps of 1.25°

Transmitter and receivers

Frequency : 222.4 + 0.2 n (n = 0, ...15) MHz (i.e. 16 frequencies)
Peak power : 5 MW
Maximum duty cycle : 12.5%
Maximum pulse repetition rate : 1000 Hz
Pulse length : 10-1000 μs.
System temperature : ∿ 340°K
Number of receiver channels : 8

Experiment SP103

Pulse Scheme	Ranges Sampled (km)	Resolution (km)
Power Profile for Ne	79-442	9
5 pulse multipulse for V and T	145-505	9
Long pulse 825 μs for Ne, V and T	305-1250	135

Scans between N(90°) and S(75°) in 30 steps of 0.5° (≡ 2.6 km at 300 km range)
One scan cover 78 km at 300 km range
One experiment composes 8 scans of 10 minutes each alternating fron N-S to S-N
Total experiment time: 80 minutes
Integration time: 20 s (7 s to move, 13 s in position)

version of SP103 on the VHF system was made on 3 and 4 August 1987. The main aim of the experiment was to test the sensitivity of the equipment in detecting irregularities up to 1250 km range. Details of the experiment are also included in Table 2. It differs markedly from the UHF experiment in Table 1. In order to extend the scan range up to 1250 km and to allow enough information to be recorded for extracting temperatures and drift velocities, the experiment is in three parts. The specifications can be changed with future experience. On both occasions the experiment was run to coincide with a HILAT pass.

4. Runs of SP103 (UHF and VHF) to date

Table 3 summaries the runs of SP103 made to date with both UHF and VHF radars. Information is also provided on those runs where a coincident HILAT pass occurred. Since the beginning of the project 15 runs have been made, not counting double runs. Some of the more recent runs were made during the daytime. The planning of SP103 was originally influenced by forecasts of geomagnetic activity. To obtain good coincidence with HILAT passes, SP103 runs have to be planned so that they take place when the satellite is at high elevation over Tromsø (typically > 80°). Consequently it is not so easy to select a day when high activity is predicted. Since 1984 only the 1986 March 13 run took place on a magnetically disturbed day.

5. Analyses of Special Program data and HILAT data

Since the installation of the new NORD computer at RAL (mid 1984), more efficient access to EISCAT tapes has been possible. However, at the beginning of the present reporting period it was necessary to spend time transferring and rewriting software from the IBM computer previously used at RAL. Most of the tapes have now been accessed for electron

Table 3 Summary of EISCAT runs of SP 103 and HILAT overpasses

DATE	EISCAT Time (UT)	Stations Tromsø = T, Kiruna = K, Sodankyla = S	Hilat		K_p	SP103 details		
			Time (UT)	Max. elev.		Version	No. of sections	No. of ranges
1981 Dec 17	1500–1700	T,K,	-	-	2–	±50 km scans	10	12
1982 June 3	1100–1300	T,K,S	-	-	2+/2	±50 km scans	10	12
1982 Nov 29–30	2115–0036 (2 runs)	T,K,S	-	-	5–/4	±64 km scans	11	16
1983 Dec 5–6	2310–0051	T,K	2333	78°	4–/3+	±64 km scans E region	11	14
1984 Feb 9	2100–2300	T,K	-	-	3–	Searching mode	-	14
1984 Feb 10	2100–2300	T,K	-	-	5	±64 km scans E region	11	14
1984 Dec 15	0820–1100 (2 runs)	T,K,S	0928	86°	3–	±64 km scans	10	16
1984 Dec 15–16	2300–0150 (2 runs)	T,K,S	0027	82°	6–/4	"	10	16
1985 Dec 9	1128–1256	T,S	1211	81°	0+	"	10	16
1985 Dec 12	1003–1125	T	1053	51°	1	"	10	16
1986 Jan 8	0703–0801	T,K,S	0734	64°	2+	"	10	16
1986 Mar 13	1415–1545	T,K	1459	86°	4–	"	10	16
1987 Feb 19	1823–2010	T,K,S	1909	70°	2–	Stationary positions ±64 km	11	16
1987 Aug 3	0732–0845	T	0806	81°	* 2	VHF 78 km scans	8	?
1987 Aug 4	2202–2345	T	2238	85°	* 3	VHF 78 km scans	8	?

* Preliminary values

densities, but the recent VHF experiment will require new software to be written before the data can be looked at in detail. Tapes of data from all the coincident HILAT passes have been sent directly to Lancaster where all but the most recent have been read. Initial problems were encountered with these tapes since the data were written in a format not directly readable on the Lancaster mainframe. Most of the data on the tape were written in 32-bit Hewlett Packard real word format (with the exception of some 16-bit integers). These had to be converted into their VAX equivalent formats which required a manipulation of the bit placements in each word. Files from tape first had to be dumped to disk in hexadecimal code and then the conversions were made. The software to carry out the conversions were written at Lancaster by CIB. Table 4 gives a summary of the state of analysis of both EISCAT and HILAT data.

5.1 EISCAT data: irregularities of electron density and electron content in the auroral zone

Analysis of data from the run of 1982 November 29/30 has continued, since this detected the most intense irregularities seen to date. The RAL analysis program has been used to determine ion drift velocities and ion and electron temperatures. Good agreement was seen between measurements from the latest version of the analysis program and the older version used by Kirkwood in 1983. The data were post-integrated over periods of one or two minutes. So far, data from three experiments have been analysed in this way.

New software has enabled data to be displayed in contour format and for electron densities to be integrated to give electron content and its variations with time. Recent results from this analysis and from the analysis of irregular structures in the F-region have been

Table 4 Summary of Data Analysis

Date	EISCAT DATA	HILAT DATA
1981 Dec 17	System performing poorly. No irregularities seen. Analysed in detail and shown that variations no larger than system noise	
1982 June 3	Daytime. No irregularities seen. No analysis planned	
1982 Nov 29-30	Irregularities present. Analaysed in detail for correlation size, velocities, temperatures etc.	
1983 Dec 5-6	Irregularities present. Analysed in detail for correlation size, velocities, temperatures etc.	Data retrieved from tape - Summary data plotted
1984 Feb 9	Tapes at RAL, not accessed. Electron densities low	
1984 Feb 10	Irregularities present. Analysed in detail for correlation size, velocities, temperatures etc.	
1984 Dec 15	Data accessed. Electron densities very low - some features visible in the E region	Data retrieved from tape Summary data plotted
1984 Dec 15-16	Data accessed. Electron densities still very low with most activity occurring towards the E region	Data retrieved from tape Summary data plotted
1985 Dec 9	Data accessed. Electron densities very low. No irregularities seen.	Data retrieved from tape
1985 Dec 12	" "	"
1986 Jan 8	" "	"
1986 Mar 13	Data accessed. Irregularities present in lower F-region	"
1987 Feb 19	Data accessed. Quality of data is suspect	Tape available
1987 Aug 3	Tapes not yet available	Tape not yet available
1987 Aug 4	" " " "	" " " "

presented in two papers (Hargreaves et al., 1985b; Hargreaves and Burns, 1987). The three periods studied were November 29/30 1982, December 5 1983 and February 10 1984. The results are summarised as follows:-

1. The magnitude of the irregularities varies significantly with range. At the greatest ranges the measurements become increasingly noisy, though real irregularities may be present as well.
2. For periodicities less than 2 minutes the irregularity magnitude peaks above the F-layer maximum. In relative terms expressed as a percentage of the mean electron density, the irregularity magnitude increases with altitude, being typically 5-10% near 200 km altitude, and 15-30% near 650 km altitude.
3. The irregularity intensity does not appear to be related to the shape of the mean electron density profile.
4. If the observed time variations are due to structures drifting through the beam then a drift speed of 500 m/s would infer spatial periods of 15-60 km (corresponding to the periodicities of 2 minutes to 30 seconds observed in the data).
5. The electron content is highly variable on time scales down to 1 minute. The magnitude of the variations ranges from 7% to 32% when expressed as a percetage of the mean electron content.
6. Major variations in electron content result from well defined enhancements of electron density with typical changes at the edges of 10^{15} m^{-2}/s, and total changes exceeding 3×10^{16} m^{-2} within 30 seconds. Enhancements range between 35 and 200 seconds duration, equivalent to 12-70 km in width (using drift velocities determined from tristatic measurements).
7. Spatial gradients of electron content vary between 4×10^{15} m^{-2}/km and 4×10^{16} m^{-2}/km. These would have significant effects on trans-ionospheric radio propagation.

8. A significant reduction in the ratio of electron temperature to ion temperature (Te/Ti) occurs during electron density enhancements in the F region. Electron density profiles are more pronounced in the F region during an enhancement.

9. Two sources of ionization are suggested - a distant source causing large enhancements which drift to the observing site in the polar convection, and a local E-region source due to energetic particle precipitation. The second type of structure appears to have less effect on the electron content than the first type.

5.2 A comparison between EISCAT and HILAT measurements of electron content

Since December 1983 we have made 10 runs of SP103 coincident with HILAT passes. It has been possible to make preliminary comparisons between measurements made by EISCAT and HILAT for the first 7 of these runs. One of the HILAT experiments measures the electron content over the raypath every 5 second along the orbit. Since variations in electron content can be large enough to affect trans-ionospheric radio propagation (Hargreaves and Burns, 1987) this is also a useful parameter to study. Table 5 lists the corresponding measurements of electron content made by HILAT and calculated from SP103 measurements for each of the 7 coincident runs. The "coincidence" is taken to be the point where the satellite is at its maximum elevation and closest to the Tromsø tracking station. Measurements from EISCAT have been taken as near to the pass time as possible. On December 5 1983 a radar malfunction caused data to be lost for several minutes, and as a consequence the nearest available measurement was 3 minutes after the HILAT pass.

Table 5 Electron contenet measurements from EISCAT and HILAT coincident times

DATE	EISCAT					HILAT				
	SCAN	TIME (UT)	AZIMUTH (DEG)	ELEVATION (DEG)	ELECTRON CONTENT x 1E + 17	TIME (UT)	AZIMUTH (DEG)	ELEVATION (DEG)	RANGE (km)	ELECTRON CONTENT x 1E + 17
1983 DEC 5	N-S	23-36-10*	179.8	78.4	0.377	23-33-19	105.2	78.1	825.7	0.894
1984 DEC 15	W-E	09-28-48	177.2	76.2	0.177	09-28-49	194.8	86.1	783.6	0.133
1984 DEC 16	W-E	00-27-20	162.5	74.6	0.114	00-27-22	319.9	82.3	796.6	0.259
1985 DEC 9	ST	12-11-04	179.8	64.8	0.150	12-11-04	215.1	81.3	791.3	1.707
1985 DEC 12	ST	10-53-12	179.8	76.5	0.128	10-53-12	100.5	51.3	969.5	1.866
1986 JAN 8	S-N	07-34-24	179.8	79.5	0.003	07-34-25	53.0	63.7	880.8	0.100
1986 MAR 13	N-S	14-59-23	179.8	69.3	0.276	14-59-22	71.9	86.1	841.5	0.676

*nearest available measurement

Figure 1 illustrates the geometry of HILAT and EISCAT coverage from Tromso for the 7 coincident passes at the time of coincidence. The arrows indicate the HILAT ascending and descending nodes. The crosses indicate the 746.5 km range gate of experiment SP103. Corresponding points are numbered in chronological order. True coincidence did not actually occur for any of the runs, so exact agreement between HILAT and EISCAT measurements cannot be expected. From Table 5 a consistent difference can be seen between TEC measured by HILAT and TEC calculated from EISCAT measurements, the HILAT values being always larger than those from EISCAT. The measurements recorded by HILAT during the December 1985 experiments seem to be abnormally high. If these two points are discarded, a linear relationship exists between the results from the two experiment techniques, the HILAT measurement being the larger by a factor of 2.2 (Figure 2).

The difference between EISCAT and HILAT results could be due to several factors. The EISCAT value was calculated by integrating electron density over the range gates 184 km to 746.5 km. Electron density below 184 km was not considered, whilst with HILAT the electron content is measured from the ground to the satellite. Neither measurement has been corrected for the slant path. These factors may account for the general difference between measurements, but it seems unlikely. They certainly cannot explain the large discrepancy between measurements made in December 1985. There is no evidence to suggest that EISCAT measurements were incorrectly calibrated at that time. The electron density profiles from all 7 runs (Figure 3) show similarities between the December '85 runs and the December 15 1984 run. However the ratio of HILAT electron content measured in December 1985 to that measured in December 1984 is approximately 13.

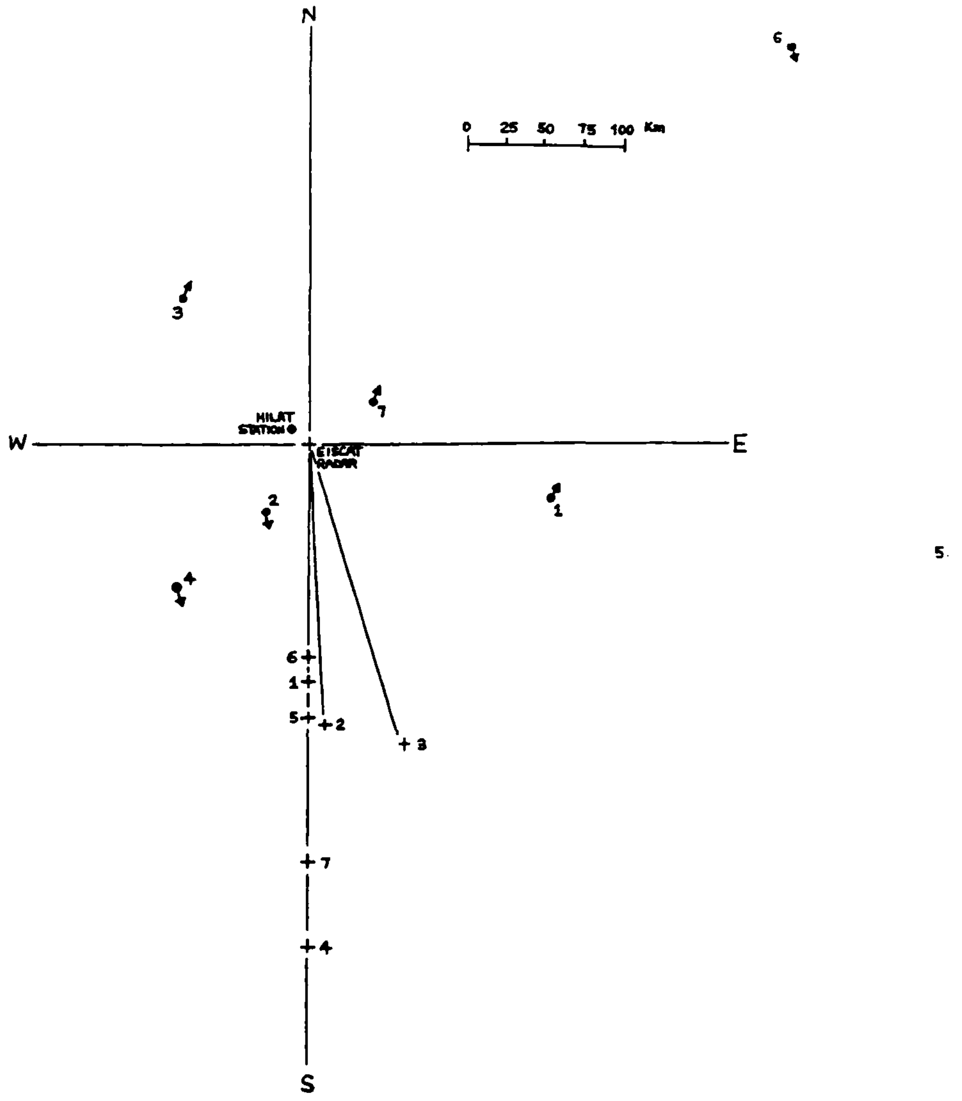

Fig. 1. The geometry of HILAT and EISCAT coverage from Tromso for the 7 coincident passes at the time of coincidence. Arrows indicate the HILAT ascending and descending nodes. Crosses indicate the 746.5 km range gate of experiment SP103. Points are numbered in chronological order. The EISCAT site (69.6°N, 19.2°E) and HILAT tracking station (69.7°N, 18.95°E) are shown.

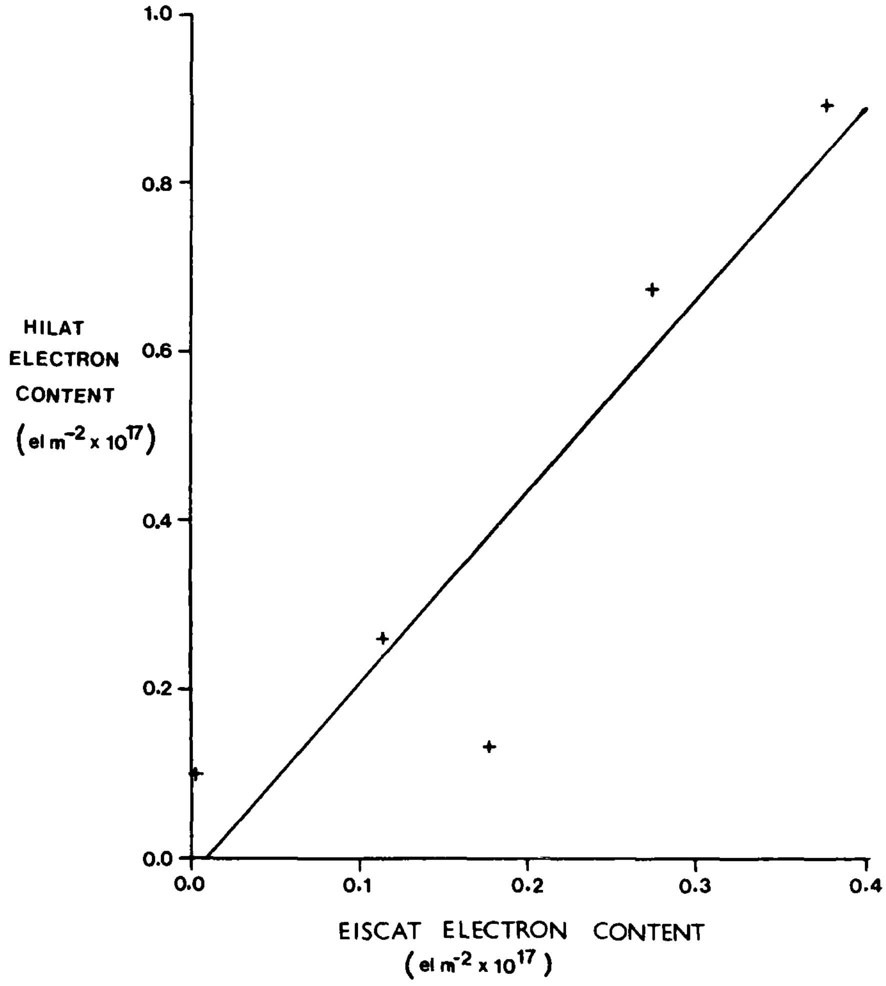

Fig. 2. Electron content measured by HILAT versus electron content as calculated from experiment SP103. The line of least regression has a slope of 2.2.

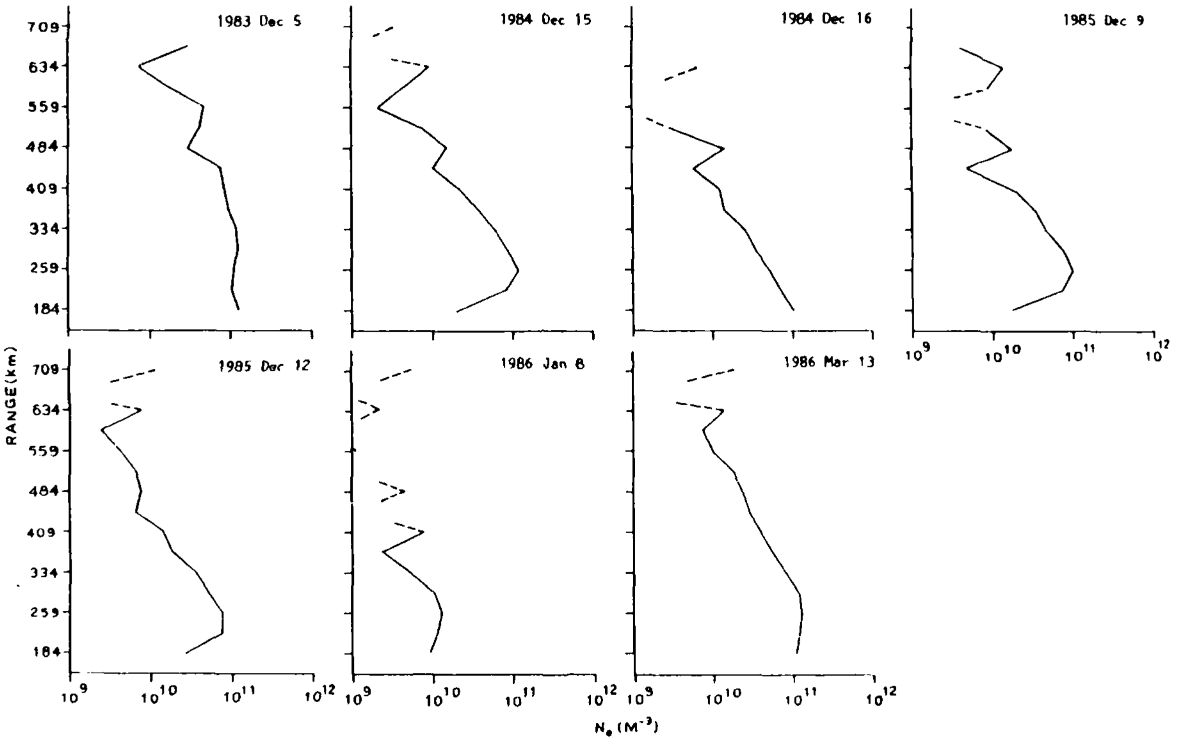

Fig. 3. Electron density profiles derived from EISCAT measurements at the times of coincidence for each coincident pass. Dashed lines indicate low signal returns from the ionosphere.

Electron content has been found to be highly variable on time scales down to a minute (Hargreaves and Burns, 1987). The largest difference observed was on 1982 November 29/30 during the second stationary period of 512 seconds, when the difference between maximum and minimum was 1.89×10^{17} m^{-2}. This is similar to the discrepancy between HILAT and EISCAT measurements on December 9 and 12, 1985 (1.56 and 1.74×10^{17} m^{-2} respectively). If this variability in electron content was the cause of the discrepancy in measurements then one would expect to see evidence for this in the variation of electron content with time. Figure 4 displays the variation of electron content over the 512-second period centred on the HILAT pass of December 1985. Also shown are contours of electron density for the same time period. The largest difference in electron content is approximately 0.08×10^{17} m^{-2}. Another example of the electron content variation with time is shown in Figure 5 for the run of March 13 1986. This was made on a more active day and here the largest difference is approximately 0.2×10^{17} m^{-2}. If these examples indicate the variability in the vicinity of the experiments it is clearly not sufficient to account for the large discrepancy between the measurements. It appears more likely that the HILAT measurements of December 1985 were incorrectly calibrated. This could be confirmed by inspecting the Tromsø ionograms for those days.

6. Publications

The following papers have been given on the experiments and results:

J.K. Hargreaves, C.J. Burns and S.C. Kirkwood : Irregular structures in the High Latitude F-Region observed using the EISCAT Incoherent Scatter Radar. AGARD Conference Proceedings 382, p6.2-1. Fairbanks, Alaska (1985).

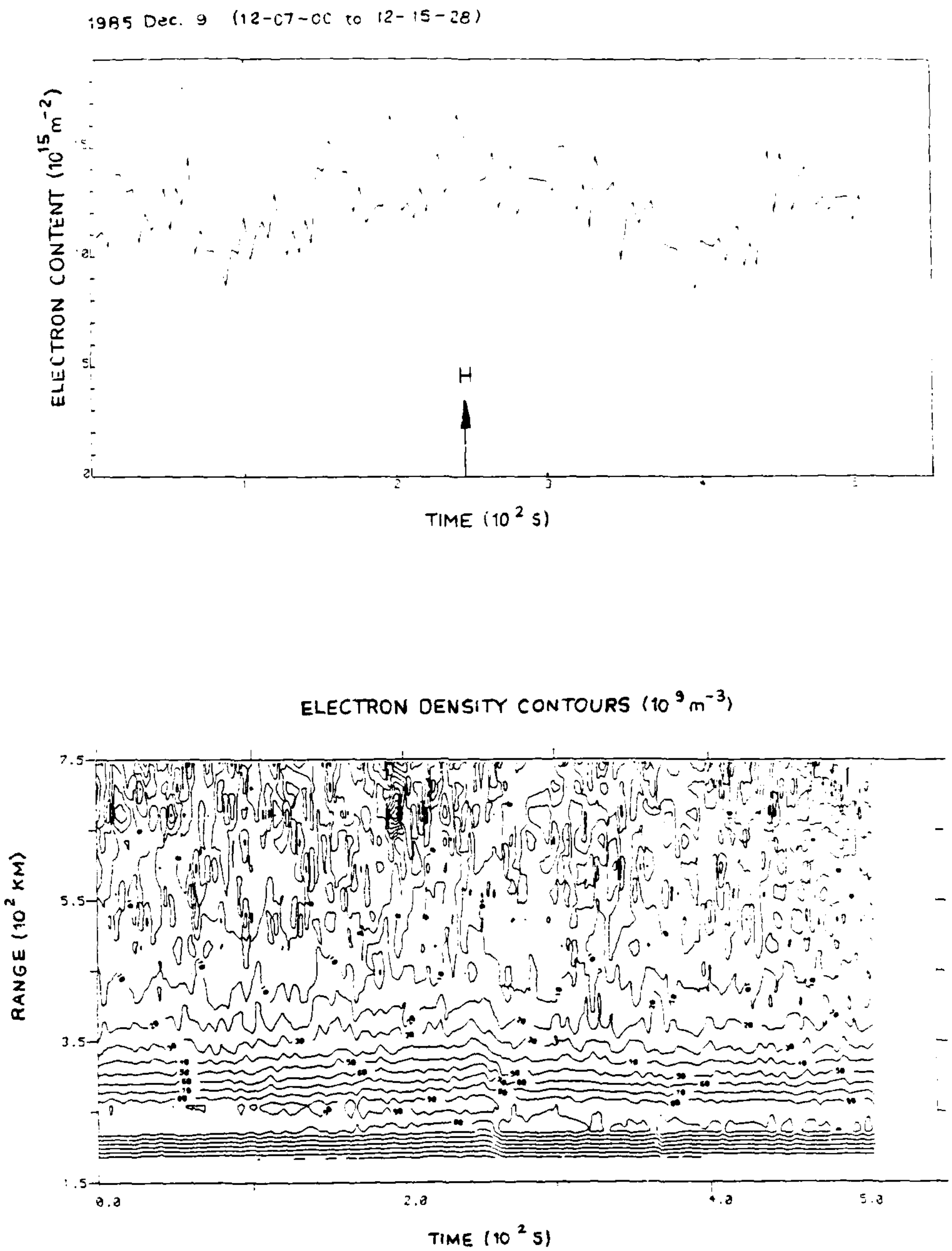

Fig. 4. Electron content (10^{15} m^{-2}) and electron density contours (10^9 m^{-3}) for the 512 second period centred on the HILAT pass time (H) of December 9 1985. The range scale (184 to 746.5 km) corresponds to the start of the 37.5 km range gates.

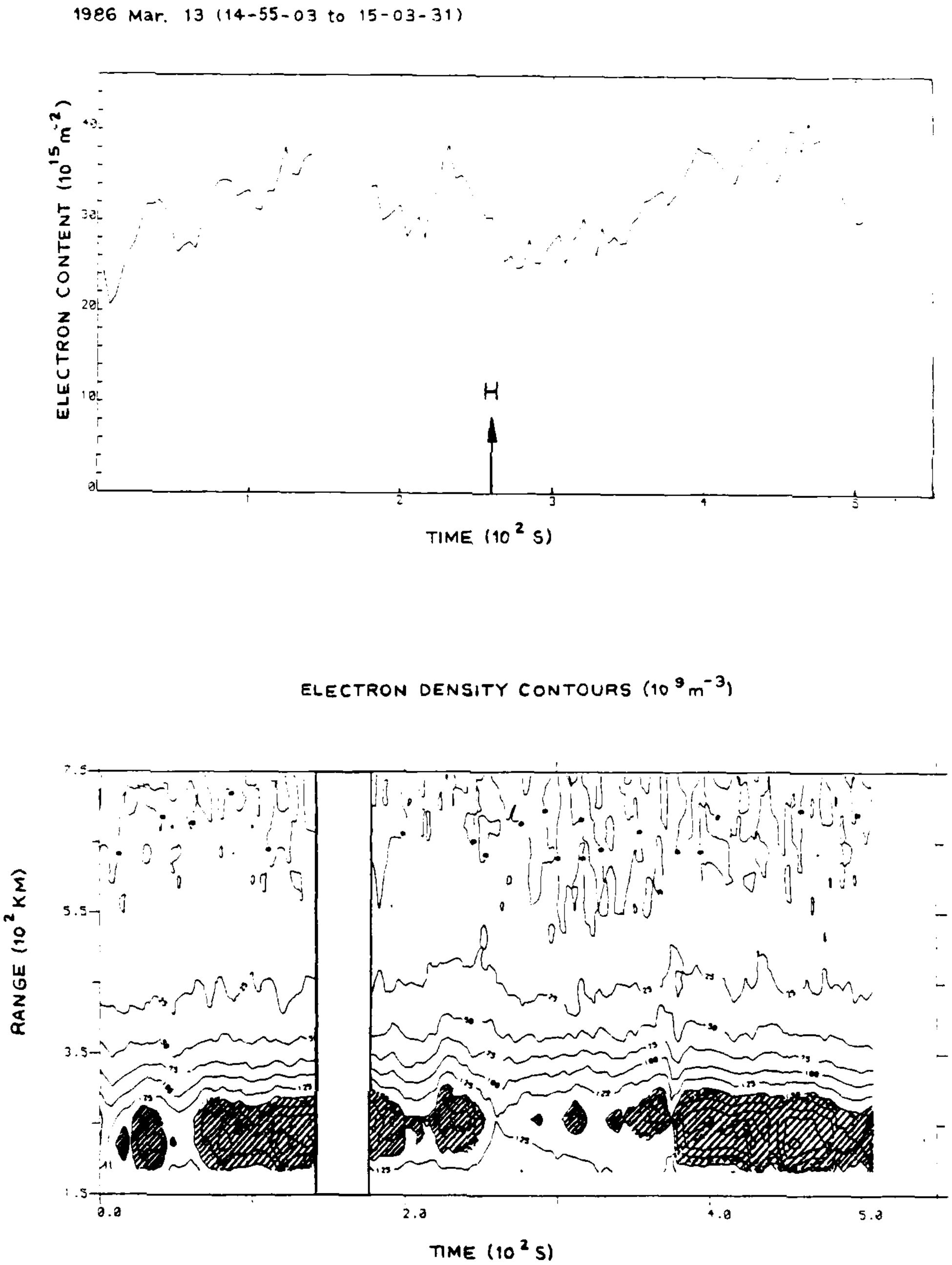

Fig. 5. Electron content (10^{15} m^{-2}) and electron density contours (10^9 m^{-3}) for the 512 second period centred on the HILAT pass time (H) of March 13 1986. The range scale (184 to 746.5 km) corresponds to the start of the 37.5 km range gates. Shading indicates electron density exceeding 1.5×10^{11} m^{-3}.

J.K. Hargreaves and C.J. Burns : Electron Density and Electron Content Fluctuations in the Auroral Zone. Ionospheric Effects Symposium, Virginia (May 1987).

7. Future Work

There remains a great deal of work to be done with the data obtained so far. Most of the time during the present reporting period has been spent in retrieving and setting up data ready for analysis. All the runs after February 1984 need to be analysed for irregularity magnitudes, periodicities, ion and electron temperatures and velocities. Runs where no irregularities appear to be present are still useful in that they provide information on the quiet time behaviour of the F-region.

Further comparisons between HILAT and EISCAT measurements should be made. HILAT supports a radio propagation experiment which is influenced by small irregularities. It has in-situ detectors for ion density, ion drift, ion temperature and mass, and it carries a 16-channel particle detector for 20 ev-20 kev electrons. All these measurements are relevant to irregularities studied by EISCAT. Although exact space/time coincidence is unlikely to be achieved, near coincidence is still of interest as showing the properties of the irregular F-region measured in the same vicinity by different techniques.

Once the VHF radar experiment has been verified future experiments may involve the split-beam mode. This allows simultaneous observation with two halves of the antenna pointing independently. From this it will be possible to determine a velocity component in the direction of the beam separation. It should also be possible to skew the beam by phasing so that one beam can observe west of the local field-line and the other to the north or south. This would allow the irregularity velocity to be determined in two dimensions.

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(Further references are included in the appendices).

Acknowledgements

This project has been supported by the Air Force Office of Scientific Research through the European Office of Aerospace Research and Development. The experiments were run at EISCAT during U.K. campaigns and thanks are due to the EISCAT Group at the Rutherford Appleton Laboratory for their support. The assistance of J.A. Klobuchar and R.C. Livingston in providing copies of HILAT data is appreciated.

APPENDIX 1

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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PROPAGATION EFFECTS ON MILITARY SYSTEMS IN THE HIGH LATITUDE REGION

NORTH ATLANTIC TREATY ORGANIZATION

IRREGULAR STRUCTURES IN THE HIGH-LATITUDE F-REGION OBSERVED USING THE EISCAT INCOHERENT SCATTER RADAR

J.K. Hargreaves, C.J. Burns and S.C. Kirkwood*
Department of Environmental Science
University of Lancaster
Bailrigg, Lancaster LA1 4YQ
England

SUMMARY

An EISCAT experiment using beam scanning has been devised to investigate small structures in the F-region at high latitudes. The paper considers the magnitude of irregularities as observed in four runs between late 1982 and early 1984. For periodicities shorter than 2 mins. the standard deviation of the electron density as a percentage of the mean electron density increases with altitude and can be as large as 30% at altitudes above 600 km. The irregularities studied have periods between about 2 mins. and 30 sec., which corresponds to spatial periods in the range 15-60 km if the drift speed is 500 m/s.

1. INTRODUCTION

As an approach to studying irregular and relatively small-scale structures in the auroral F-region, a program has been developed to scan the beam of the EISCAT UHF radar over a small region of the ionosphere, the region being scanned several times in the course of a run lasting about 90 minutes. The experiment is sensitive to irregularities several kilometres across and more since the UHF beam covers some 3 km at range 300 km, and the radar sensitivity for typical electron densities in the F-region enables variations of a few percent in the electron density to be detected in a time less than 10 s near the F-region maximum. First analysis of the data (Hargreaves et al., In press) has shown that it is possible from the experiment to determine the presence of irregular structure to above 750 km in some cases, and to estimate its magnitude, to observe how the degree of irregularity varies from time to time during a run, to observe periodicities in the structure, and to estimate the velocities of individual field-aligned structures.

When possible, runs have been timed to coincide with other observational opportunities such as passes of the HILAT satellite which measures a wide variety of properties including electron density, temperature and plasma drift velocity (HILAT Science Team, 1983).

The data can be treated in various ways to study different properties of the ionospheric irregularities. The present paper discusses their magnitudes as observed in four runs between late 1982 and early 1984.

2. BEAM-SCANNING EXPERIMENT

The concept of the experiment is illustrated in Fig. 1. In its latest form all scans of the beam are referred to the local geomagnetic field direction; the beam describes a cross having arms 64 km long at 300 km range, oriented north, south, east and west. Since the local magnetic field is inclined 13.5 deg. to the vertical at the transmitter site (Ramfjord, 69.6 deg. N, 19.2 deg. E), the 64 km scan means that at its northern most extreme the beam is just short of the zenith. The beam steps along by 2 km at a time (at the 300 km level) and the returned signal is recorded for 4 s at each step. Another 4 s is allowed for the beam to move between steps, but data are taken continuously giving an effective beam speed of 250 m/s at 300 km range with no data gaps. The range resolution is 37.5 km and in the main experiment ranges from 184 km to at least 600 km are recorded. (E-region measurements at greater range resolution have been included in the more recent runs.)

The normal order of scans is

St, S-N, N-S, S-N, N-S, St, E-W, W-E, E-W, W-E, St,

giving 11 sections. A sweep from south to north, for example, takes 512 s, and stationary periods (St) where the beam is pointed along the magnetic field for 512 s are included in the sequence. One complete run takes about 90 min. For detailed studies each section would be delayed separately, but to assess the slower variations it is also useful to display the whole run since all data refer (at 300 km range) to points within 64 km of the field direction.

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* Now at EISCAT Scientific Association, Tromsø, Norway.

Table 1 summarises the runs made to date and the state of data reduction.

3. SAMPLE RESULTS

Figure 2 illustrates typical observations in a convenient format. Electron density is plotted as ordinate and is placed on the diagram so that the mean value is at the level of the range mark. The abscissa shows time in seconds. Figure 2a is from a period with strong irregularities, whereas in Figure 2b the irregularities are much weaker. Since the beam was pointed along the geomagnetic field at these times it may be seen that the irregularities, as would be expected, are essentially field aligned.

There is plainly a considerable difference in irregularity intensity between these two examples although the observations are both from the same run. These examples also show a significant variation with range. The irregularity magnitude is obviously smaller at the lower altitudes; at the greatest ranges the measurements become increasingly noisy, though true irregularities are certainly present in the random noise.

4. IRREGULARITY MAGNITUDE AND ITS HEIGHT VARIATION

The runs of November 29-30 1982, December 5-6 1983 and February 10 1984 are comparable in that they were made in the late evening in winter using essentially the same observing program. A HILAT pass occurred during the run of December 1983.

Taking the standard deviation of the electron density as a percentage of the mean electron density during the scan gives values ranging between 3% and 62% at 184 km (the shortest range), and between 15% and 91% at 597 km. After filtering to remove periods greater than 2 min. the standard deviation ranges are 2-19% at 184 km and 12-66% at 597 km. Power spectra confirm visual impressions that the variations at lower altitudes represent real structures, whereas those at the highest levels are mainly random errors due to experiment noise. The spectra shown in Fig. 3a, which were derived from the electron density values of Fig. 2a, show marked periodicities of 152 s and 65 s which are each coherent over a range of heights. Such features are not seen at the greatest heights.

To compensate for the experiment noise, values of the variance during the quieter sections may be averaged and subtracted, height for height, from the variance during the more disturbed sections of the run. Assuming that the experiment noise did not change with the intensity of the irregularities this procedure enables us to quantify the height variation of the irregularity magnitude. (Should there have been some irregularities during the quiet periods - as there well may have been - the procedure gives a *least value* for the variance due to irregularities, and still measures the *change from quiet to disturbed conditions*).

The level of experiment noise depends on the parameters of the radar and on the electron density as a function of range. During the runs of 1982 November 29-30 the electron density profile (Fig. 4) changed relatively little and thus the experiment noise should have been almost constant throughout at any given range. There is no apparent association between the shape of the electron density profile and the intensity of irregularities. In Fig. 4, which shows the profiles during the 6 sections of the runs when the beam was stationary, irregularities were weak during sections 3 and 5, but strong during the other sections.

Fig. 5 shows the vertical structure of the irregularity magnitude as derived by the above procedure, the data having been filtered to remove periodicities longer than about 2 minutes. In absolute terms the standard deviation is largest in the topside ionosphere somewhat above the F-layer maximum. In relative terms, expressed as a percentage of the mean electron density, it increases indefinitely with altitude up to at least 750 km. In deriving these values the variance subtracted exceeded that remaining for heights above about 600 km.

A similar procedure has been applied to the run of 1983 December 5-6, and a similar result was obtained (Fig. 6a). The relative standard deviation varies from 4% at 184 km to 28% at 671 km. (For the reasons given above this will be an underestimate rather than an overestimate.) It is interesting that the shape of the F-region changed markedly during this run (Fig. 7a) but this change was not accompanied by any obvious change in the magnitude of the irregularities. The experiment noise increased at the greater heights as the electron concentration decayed, as would be expected; for this reason the last few sections, when the decay was most rapid, were not included in the analysis leading to Fig. 7a.

In the run of 1984 February 10 (Kp = 5) every section showed irregularities and there was no quiet period against which to compare. Subtracting the smallest variances, from wherever they occurred, from sections 1-4, which appeared to be most active, leads to the results of Fig. 6b. Again the electron density profile changed greatly towards the end of the run (Fig. 7b).

5. CHARACTERISTIC PERIODS AND SPATIAL WAVELENGTHS

The run of February 1984 proceeded without significant breaks, and these data are particularly suitable, therefore, for spectral analysis. Figure 8 shows the power spectral density as a function of range, taken over the whole run for the filtered data. The high-pass filter used (a simple moving-point average) transmitted half power at frequency 8.16×10^{-3} Hz, period 122.5 s; this frequency is marked on Fig. 8. It is seen that most of the power is in periodicities longer than about 30 s, and that the power measured at periodicities below 24 s is mainly noise. Although we have tried to emphasise the shorter periods in this study of the magnitude of the irregularities, there is considerably more power at longer periods.

Assuming that the observed time variations arise because of spatial structures drifting through the beam, a knowledge of the drift speed would enable us to convert the time spectrum to a spatial spectrum. The lower scale of Figure 8 shows the distance scale on the assumption of 500 m/s drift speed.

6. CONCLUSIONS

1. Field-aligned irregularities on scales exceeding a few kilometres can be detected by the EISCAT UHF radar to heights of around 700 km.

2. In four night-time, winter runs studied, the magnitude of the irregularities comes to a maximum at or somewhat above the F-region electron density peak; including only periodicities shorter than 2 minutes, their relative magnitude increases with height, being typically 5-10% of the mean electron density at heights near 200 km, and 15-30% near 650 km.

3. Although the irregularity intensity varies greatly over periods of tens of minutes, there is no apparent relationship between intensity of irregularities and shape of the mean electron density profile.

4. The irregularities quantified by this analysis are in a frequency band 8×10^{-3} to 4×10^{-2} Hz (periods 122 s to 25 s), the lower limit being set by the filter used. Irregularities are not observed above the higher limit. If a drift speed of 500 m/s is assumed this frequency band corresponds to spatial wavelengths of 15-60 km.

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J.K. Hargreaves, C.J. Burns and S.C. Kirkwood
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ACKNOWLEDGEMENTS

The experiments were run at EISCAT during U.K. Campaigns and thanks are due to the EISCAT Group at the Rutherford Appleton Laboratory of the Science and Engineering Research Council for their support. The project has been funded by the Air Force Office of Scientific Research under grants 81-0049, 83-0054 and 83-0371.

Table 1

Summary of EISCAT runs of SP 103

Date	Time(UT)	Kp	Program	Comments
1981 Dec 17	1500-1700	2-	±50 km scans	System performing poorly. No irregularities seen. Analysed in detail and shown that variations no larger than system noise.
1982 June 3	1100-1300	2+, 2	±50 km scans	Daytime. No irregularities seen. No analysis planned.
1982 Nov 29-30	2115-0035 (2 runs)	5-, 4	±64 km scans	Irregularities present. Analysed for magnitudes, spectra and velocities
1983 Dec 5-6	2310-0050	4-, 3+	±64 km scans E region	HILAT pass at 2333 UT. Irregularities analysed for magnitudes and spectra.
1984 Feb 9	2100-2300	3-	Searching mode	Tapes at RAL, not yet accessed. Electron densities low.
1984 Feb 10	2100-2300	5	±64 km scans E region	Irregularities present. Analysed for magnitudes and spectra.
1984 Dec 15	0820-1100 (2 runs)	3/4*	"	Tapes at RAL, not yet accessed. HILAT pass at 0927 UT.
1984 Dec 15-16	2300-0150 (2 runs)	5/4*	"	Tapes at RAL, not yet accessed. HILAT pass at 0026 UT.

* Preliminary values

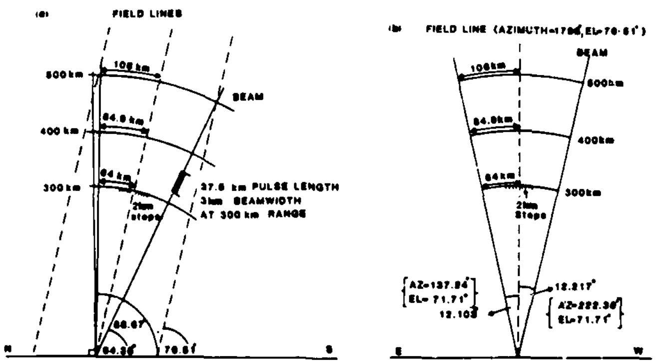

Fig. 1. Scans of the UHF radar beam. Each scan is made up of 64 steps and takes 512 seconds:
(a) Elevation (N-S) ; (b) Azimuth (E-W).

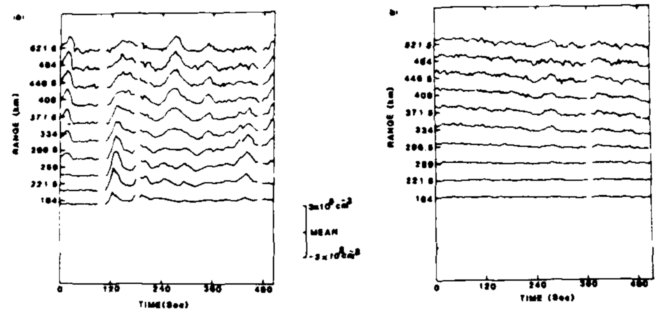

Fig. 2. Examples of electron density variations seen with the beam stationary, 1982 November 29:
(a) 2115-2123 UT, showing strong irregularities;
(b) 2242-2251 UT, showing weak irregularities.

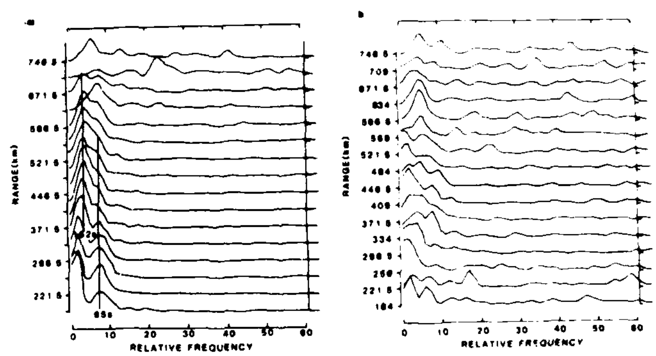

Fig. 3. Normalised power spectra for the observations shown in Figure 2, mean and linear trend having been removed:
(a) 2115-2123 UT, showing periodicities of 152 s and 65 s;
(b) 2242-2251 UT, showing mainly noise.
The frequency unit is 1.98×10^{-3} Hz.

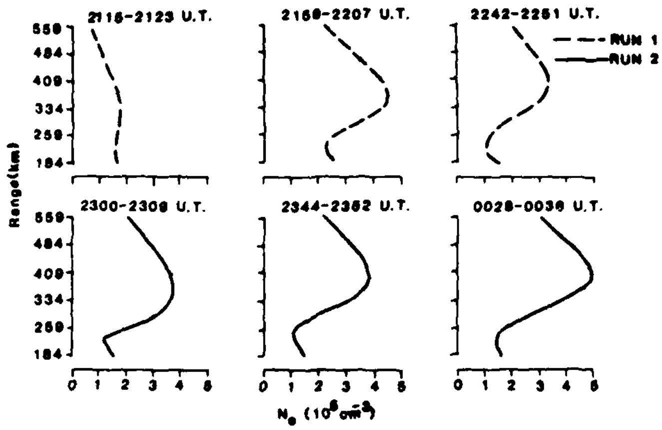

Fig. 4. Mean electron density profiles on 1982 November 29-30, stationary beam.

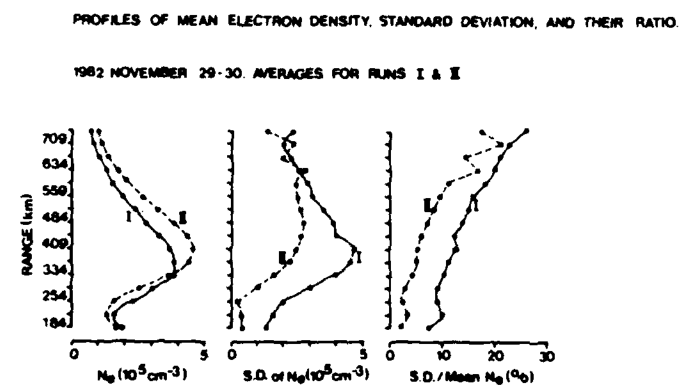

Fig. 5. Vertical structure of irregularity magnitude, 1982 November 29-30, after correction for experiment noise.

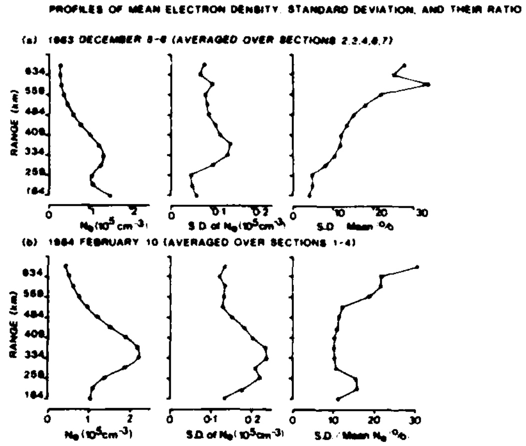

Fig. 6. Vertical structure of irregularity magnitude:
(a) 1983 December 5-6;
(b) 1984 February 10.

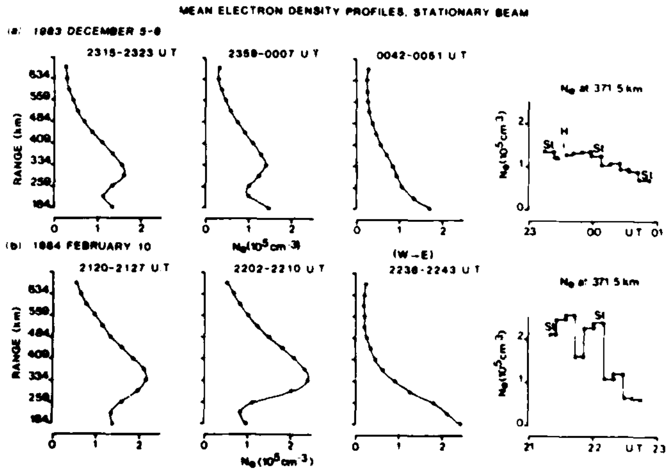

Fig. 7. Mean electron density profiles and variation of electron density at 371.5 km range:
(a) 1983 December 5-6;
(b) 1984 February 10.

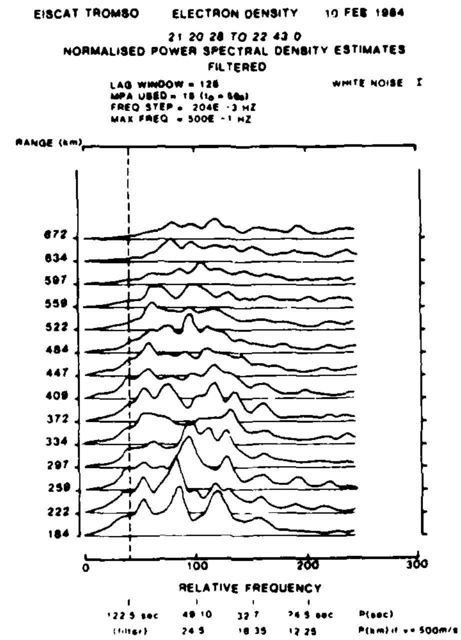

Fig. 9. Normalised power spectra over the whole of the run on 1984 February 10. The frequency unit is 2.04×10^{-4}Hz, and a high-pass filter (8.16×10^{-3}Hz) was applied.

DISCUSSION

A.Rodger, UK

Have you investigated the ion and electron temperature within the irregularities and compared these with corresponding temperatures of the ambient plasma?

Author's Reply

Lack of time has prevented this being investigated, but it would certainly be interesting to do so as something that might shed light on the origin and age of the irregularities observed.

Ionospheric Effects [illegible],
Springfield, Virginia, [illegible].

ELECTRON DENSITY AND ELECTRON CONTENT FLUCTUATIONS IN THE AURORAL ZONE

J.K. Hargreaves and C.J. Burns
Department of Environmental Science
University of Lancaster
Lancaster LA1 4YQ
England

ABSTRACT

High-latitude observations of electron density by means of incoherent-scatter radar have been integrated to give electron content up to about 700 km altitude. The electron content is found to be highly variable on time scales down to a minute, and the variations are large enough to have significant effects on trans-ionospheric radio propagation. In some cases the horizontal velocities of the enhancements, and their temperatures, have been determined. It is likely that more than one source is involved.

INTRODUCTION

Since 1981 a programme to investigate the fine structure of the auroral F-region has been conducted using the EISCAT incoherent-scatter radar system in Scandinavia. The measurements have a time resolution of 4 seconds, a range resolution of 37.5 km, and samples are taken out to nearly 750 km range. The experiment includes north-south and east-west scans as well as periods when the radar looks directly along the geomagnetic field from Tromsø. The returns are also received at the Kiruna and Sodankylä remote stations so that plasma drift may be determined in three dimensions. The experiment and previous results have been described by Hargreaves et al. [1985 a,b]. Some details are given in Table 1.

APPLICATION TO ELECTRON CONTENT

One objective of the project is to see how the F-region irregularities in the auroral ionosphere affect the electron content. Being field-aligned, the irregularities will have greatest effect in the direction of the geomagnetic field, and in the present study attention is therefore confined to periods of observation when the radar was directed along the geomagnetic field from Tromsø; that is, pointing almost due south at elevation 76.5°. At this elevation the nearest and furthest range gates, 184 and 746.5 km, correspond to heights of 179 and 726 km respectively. The electron content is obtained by summing the electron density over all the range gates recorded.

Table 2 shows the sections of data that have been integrated in this manner. Each section is nominally 512 s long (nearly 9 min) and comprises 128, 4-second values. Small gaps within these sections have been filled with interpolated values. All of these runs were in the midnight sector.

MAGNITUDE OF ELECTRON CONTENT VARIATIONS

The variations of calculated electron content over 512-s intervals are illustrated in Figures 1-3. Figure 1 shows the period with the greatest degree of irregularity. Figure 2 shows a single enhancement of electron content, a feature which has been seen on three separate occasions. Figure 3 is the least irregular period of the data set. For these three periods, the ratio of standard deviation to mean is respectively 32%, 26% and 7.3%, and the ratio of maximum to minimum value (during 512-s) is respectively 3.8, 2.5 and 1.4. Table 3 gives the magnitude of the fluctuations for all the periods analysed. The total range of electron content variation within 512-second periods was from 2.4×10^{15} m^{-2} to 1.9×10^{17} m^{-2}, with median 4.4×10^{15} m^{-2}.

Comparing the electron content variations with the contour plots of electron density shows that the major variations of electron content result from well defined enhancements of the F-region. Some of these enhancements have sharp edges; the resulting rapid changes of electron content may exceed 10^{15} m^{-2}/s and the total change at an edge may exceed 3×10^{16} m^{-2} within half a minute. Table 4 notes the largest rate of change of electron content observed in each section analysed.

DRIFT VELOCITY AND SPATIAL SIZE

If the observed time variations are due to spatial structures moving through the fixed radar beam then a measurement of the velocity will enable the observed temporal variations to be interpreted as spatial variations. Tristatic velocity data were obtained for the runs of November 1982, and the eastward (V_E), northward (V_N), and field-aligned ($V_{||}$) components of velocity are given in Table 4. In December 1983 and February 1984 data were obtained only from Tromsø and Kiruna; for these periods, therefore, only the field-aligned velocity and the horizontal component between Kiruna and Tromsø (V_{K-T}) can be measured.

Table 1 : EISCAT UHF system and experiment SP103

Locations

	Geographic	Corrected geomagnetic	L
Tromsø (Transmitter, receiver)	69.6°N, 19.2°E	66.6°N, 104.9°E	6.17
Kiruna (Receiver)	67.9°N, 20.4°E	64.9°N, 104.2°E	5.38
Sodankylä (Receiver)	67.4°N, 26.7°E	63.9°N, 108.5°E	5.03

Antennas

Diameter : 32 m
Gain : 48 dB
Half-power beamwidth : 0.6° ≡ 3 km at 300 km range
Steerability : elevation 10°-90°
: azimuth 270°
Maximum slewing rate 80°/minute.

Transmitter and receivers

Frequency : 933.5 ± 2.5 MHz (8 frequencies in 0.5 MHz steps)
Peak power : Up to 2 MW (∿1 MW used)
Maximum duty cycle : 12.5
Noise temperature : nominally 145°K(Tromsø) .45°K(Remotes)
Pulse repitition rate : 0-1000 Hz
Pulse length : 10 μs-10 ms

Experiment SP103

Pulse sequence repitition rate : 125 Hz or 117 Hz.
Pulse lengths : 50 μs (power profile), 250 μs (tristatic), 5 × 20 μs (multipulse)
Integration time : 4 s.
One experiment comprises 10 or 11 sections of 512 s each
One scan covers 128 km at 300 km range
Experiment sequence : St, S→N, N→S, S→N, N→S, St, E→W, W→E, E→W, W→E, St
(where St ≡ field-aligned)
Range gate : 37.5 km
Ranges sampled : starting at 184 km to 671.5 km (14 gates) or to 746.5 km (16 gates).
Remote stations receive from 300 km range.
ACF's computed at 25 points with 10 μs lag.

Table 2 : Sections of data integrated for electron content

File	Year	Time (U.T.) Start	End	No. of Values	Estimated Values	K_p
NOV29AA	1982	21-15-08	21-23-32	127	4	5-
NOV29AB		21-58-48	22-07-16	128	17	"
NOV29AC		22-42-32	22-51-00	128	1	"
NOV29BB		23-43-48	23-52-16	128	1	"
DEC05A	1983	23-15-04	23-23-32	128	0	4-
DEC05B		23-58-46	00-07-14	128	0	4-, 3+
DEC05C		00-42-30	00-50-58	128	11	3+
FEB10A	1984	21-20-28	21-26-32	92	0	5
FEB10B		22-01-48	22-10-16	128	1	"

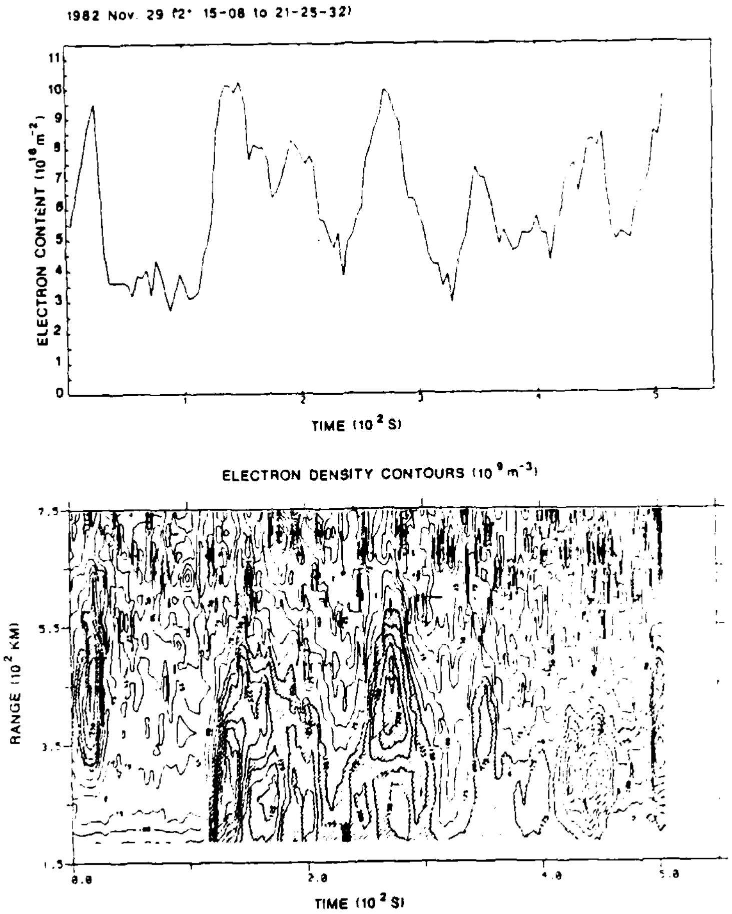

Figure 1. Electron content (10^{16} m^{-2}) and electron density contours (10^9 m^{-3}) during section NOV29AA. The range scale (184 to 746.5 km) corresponds to the start of the 37.5-km range gates. The shading indicates electron density exceeding 1.5×10^{11} m^{-3}.

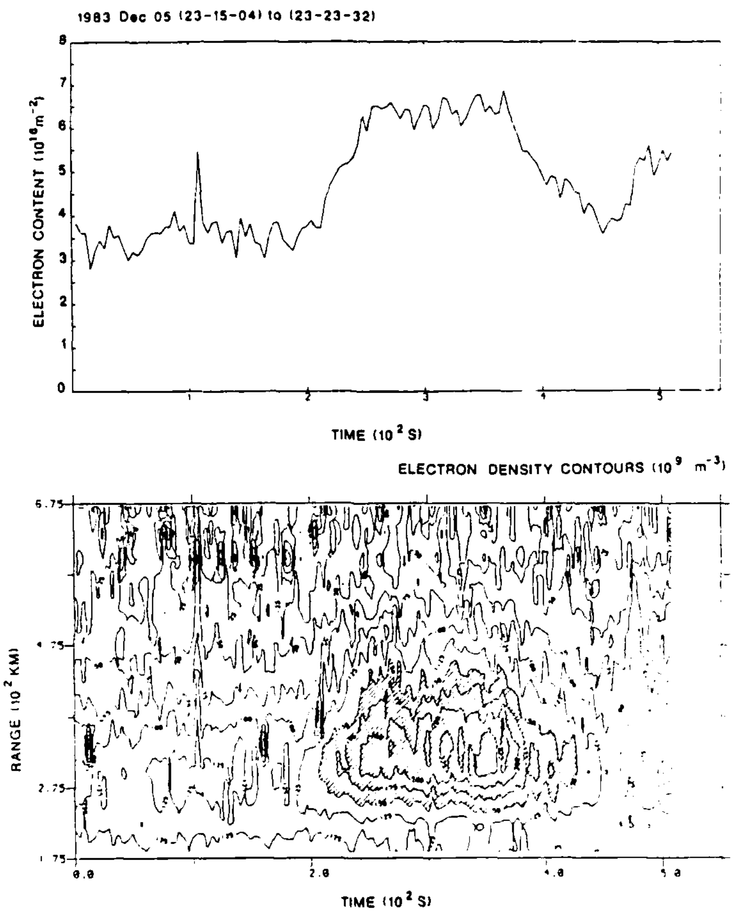

Figure 2. Electron content (10^{16} m^{-2}) and electron density contours (10^9 m^{-3}) during section DEC05A. The range scale (184 to 671.5 km) corresponds to the start of the 37.5-km range gates. The shading indicates electron density exceeding 1.5×10^{11} m^{-3}.

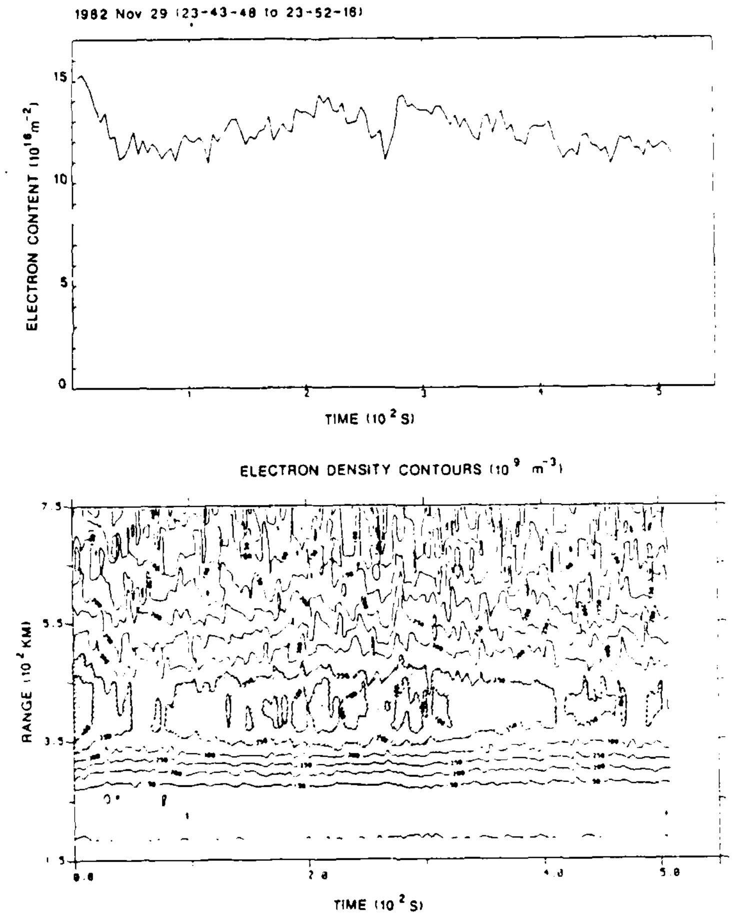

Figure 3. Electron content (10^{15} m^{-2}) and electron density contours (10^9 m^{-3}) during section NOV29BB. The range scale (184 to 671.5 km) corresponds to the start of the 37.5-km range gates. The shading indicates electron density exceeding 3.5×10^{11} m^{-3}.

Table 3 : Magnitude of electron content variations

File	Furthest range (km)	Electron content in 10^{16} m^{-2} Mean	Standard deviation	$\frac{\text{St.dev}}{\text{mean}}$(%)	Max.	Min.	Max.-min.	$\frac{\text{Max.}}{\text{min.}}$
NOV29AA	746.5	6.17	1.98	32	10.27	2.71	7.56	3.8
NOV29AB	"	15.26	4.91	32	25.53	6.61	18.92	3.9
NOV29AC	"	10.99	1.45	13	13.41	8.23	5.18	1.6
NOV29BB	"	12.54	0.92	7	15.28	10.87	4.41	1.4
DEC05A	671.5	4.70	1.20	26	6.88	2.79	4.09	2.5
DEC05B	"	4.47	0.92	21	6.28	2.50	3.78	2.5
DEC05C	"	3.38	0.50	15	4.85	2.42	2.43	2.0
FEB10A	671.5	7.20	0.59	8	9.23	6.13	3.10	1.5
FEB10B	"	7.18	1.01	14	9.12	4.43	4.69	2.1

Table 4 : Rate of change of electron content, velocity, and inferred spatial gradient

File	Max. slope (m^{-2}/s)	Change at edge (m^{-2})	Velocities (m/s) $V_{\parallel}$	V_N	V_E	V_{K-T}	$V_{Tot.}$	Inferred spatial gradient (m^{-2}/km)
NOV29AA	2.7×10^{15}	7.2×10^{16}	76	-274	199		339	8.0×10^{15}
NOV29AB	9.5×10^{15}	8.5×10^{16}	61	-259	239		350	2.7×10^{15}
NOV29AC	6.7×10^{14}	3.3×10^{16}	31	-88	161		183	3.7×10^{15}
NOV29BB	1.2×10^{15}	4.0×10^{16}	0	-21	26		33	3.6×10^{16}
DEC05A	5.2×10^{14}	2.7×10^{16}	27			-32		
DEC05B	1.2×10^{15}	2.3×10^{16}	10			-19		
DEC05C	—	—	46			-152		
FEB10A	1.7×10^{15}	1.4×10^{16}	34			-54		
FEB10B	1.3×10^{15}	3.2×10^{16}	35			—		

Although it is difficult to be sure of the accuracy of the velocity measurements, which are obtained from analysis of the spectrum of the scatter signal received at each station, we shall take them as a guide in order to comment on the likely horizontal size of some of the observed features. The main fluctuations in Figure 1 recur every 80-120 s, and a velocity of 339 m/s would imply spatial periods of 27-41 km. The typical enhancement would be about 12 km wide. The enhancement on December 5 1983, shown in Figure 2, lasted about 200 s. We have no full velocity determination for that period, but a similar structure appeared in section NOV29AB when a velocity of 350 m/s was determined. The equivalent spatial extent would be 70 km. Such distances would place the structures within Robinson et al's [1985] definition of "medium scale" (10's of km) rather than "large scale" (100's km), but within Kelley et al's [1982] "large structures" (> 10 km) category.

The rates of change of the electron content at the edge of enhancements imply spatial gradients between about 4×10^{15} m^{-2}/km and 4×10^{16} m^{-2}/km.

EFFECTS ON TRANS-IONOSPHERIC RADIO PROPAGATION

The standard deviation of electron content over a 512-s period has been found to be as high as 4.9×10^{16} m^{-2}, the smallest observed value being 10 times smaller. The range of electron content (maximum-minimum) varied from 2.4×10^{16} m^{-2} to 1.9×10^{17} m^{-2}. These variations would change the group delay of a radio signal propagating parallel to the magnetic field, and introduce range errors whose magnitudes are given in Table 5. These are calculated for one-way propagation and would be doubled in the case of radar.

We also anticipate some deviation of the wavefront due to the spatial gradient of electron content. A spatial gradient of 4×10^{16} m^{-2}/km will deviate the wavefront of a 300 MHz signal by 1°, and of a 3 GHz signal by 0.01°.

Table 5 : Estimated range errors due to group delay

Electron content (10^{16} m^{-2})	Radio frequency 3 GHz	300 MHz
Mean : 4	18 cm	18 m
15	67.5 cm	67.5 m
St.dev : 0.5	2.25 cm	2.25 m
5	22.5 cm	22.5 m
Max-min :		
2.5	11.3 cm	11.3 m
20	90 cm	90 m

TEMPERATURE MEASUREMENTS

Analysis of the spectra of the scatter signals also provides values for the electron and ion temperatures, T_e and T_i, given in Table 6. There are significant changes in both electron and ion temperature from one observing period to another, which must be related to the source and nature of the ionization being observed.

During observation period DEC05A (Figure 2) the electron temperature fell by 150° as the electron density increased, but the ion temperature was slightly increased. The ratio T_e/T_i was significantly smaller during the electron density enhancement (Figure 4). There was also a significant difference between the electron-density profiles before and during the enhancement. As shown by the average values (Figure 5a), the F-region peak was more pronounced during the enhancement. The same contrast is seen before and during an enhancement in section DEC05B (Figure 5b).

Table 6 : Temperature measurements

File	T_e(°K)	T_i(°K)	T_e/T_i
NOV29AA	1724	1285	1.34
NOV29AB	1988	1246	1.60
NOV29AC	1506	1162	1.30
NOV29BB	1442	1143	1.26
DEC05A	1391	968	1.44
DEC05B	1662	922	1.80
DEC05C	2301	1106	2.08
FEB10A	2131	1218	1.75
FEB10B	1747	1126	1.85

DISCUSSION

The variety of F-region structures within this limited sample of observations cannot be ascribed to changing season or time of day. (Those effects have still to be explored.) On the evidence of electron-density profiles and temperature measurements it appears that there is more than one source of ionization. Roble and Rees [1977] modelled the variations of electron and ion temperature, and of electron density to be expected during an auroral precipitation event. Their results showed T_e increasing sharply for the first minute and thereafter decaying slowly, T_i relatively unaffected, and electron density building up with a time constant of about 20 minutes but with a very slow subsequent delay. Enhancements like that in section DEC05A (Figures 2,4, and 5 (a)(ii)) are therefore likely to have been produced some distance away and to have reached the observation site by drifting with the convection of the polar ionosphere. (Convection at 300 m/s could transport a structure by 10° of latitude in an hour). Kelley et al [1982] argued that such enhancements, which they called "blobs", originate in soft electron precipitation at the poleward edge of the auroral oval.

By contrast, electron density profiles which seem to peak in the E-region and show greater electron temperature are likely to be due to local production by energetic particles. The variations of T_e evident in Table 6 are generally consistent with this. For example, section DEC05C, which gives the highest value of T_e, includes no enhancements peaking in the F region but several confined to the lower altitudes observed. Enhancements of this type tend to have a smaller effect on the electron content.

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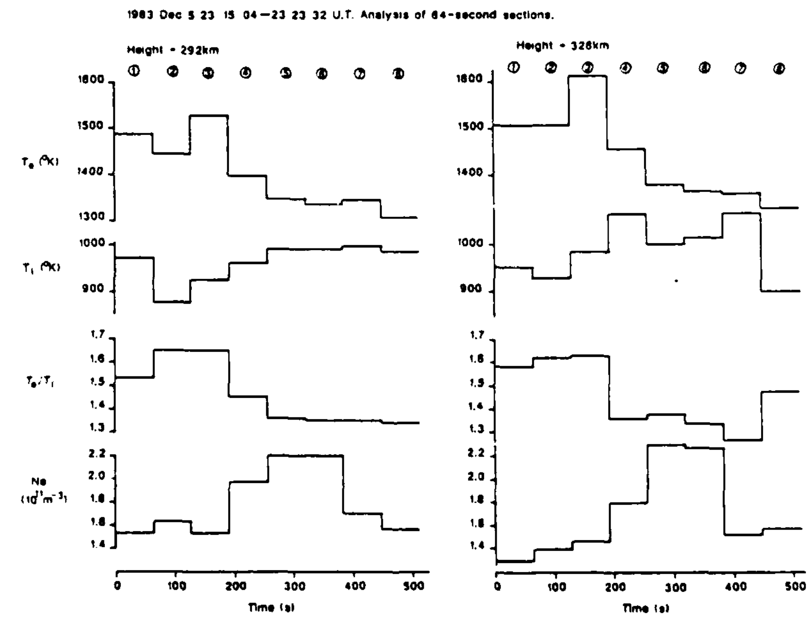

Figure 4. Electron and ion temperatures determined over 64-second intervals at two heights during section DEC05A. The electron density enhancement passed across during intervals 4-6. The electron temperature fell significantly with the approach of the enhancement.

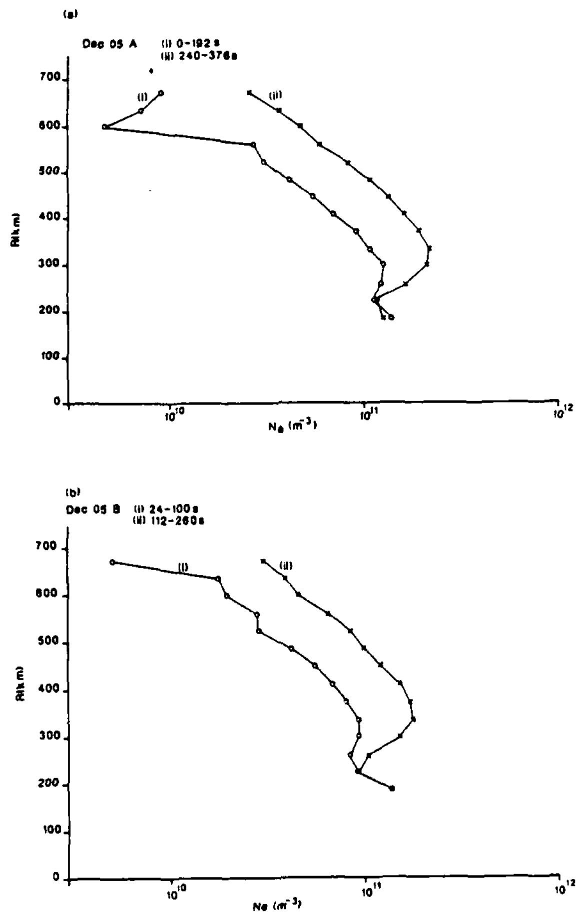

Figure 5. Electron density profiles averaged (i) before and (ii) during an enhancement. Despite their similarity, (a) and (b) are independent observations made 43 minutes apart on 1983 Dec 5.

APPENDIX 3 : PROGRAMS

PROGRAM NAME	SPECIAL ROUTINES	DESCRIPTION	AUTHORS
TAPECAT-SYSTEM	RAL tape routines	Searches the EISCAT tapes catalogue	RAL EISCAT group
TEXT-FILES	RAL tape routines	Copies text files from an EISCAT tape	RAL EISCAT group
STEER		Creates a steering file for the analysis program	Barbara Bromage RAL
ANAL	RAL tape routines	EISCAT analysis program for deriving tempera- tures, velocities etc.	RAL ESICAT group
ZLAGEX	RAL tape routines	Reads raw data files from tape and dumps zero lags to disk. Checks experiment settings	C.J. Burns
ZLAGCK	GINO (graphics)	Cleans data produced by ZLAGEX	S.C. Kirkwood C.J. Burns
ZLAGPR		Reduces zero lags to electron densities	C.J. Burns
ESTIM		Fills small data gaps with estimated values	C.J. Burns
DENPLOT	GINO (graphics)	Plots multiple time series of electron density	C.J. Burns
DENACF	GINO (graphics) NAG	Calculates and plots ACF's of electron density data for each range	C.J. Burns
DENPSD	GINO (graphics) NAG	Calculates and plots power spectra of electron density data for each range	C.J. Burns
DENSTAT		Calculates various statistics of electron density data for each range	C.J. Burns
IRRINT	GINO (graphics)	Plots contours of electron density. Integrates and plots electron content	J.K. Hargreaves

PROGRAMS (Continued)

PROGRAM NAME	SPECIAL ROUTINES	DESCRIPTION	AUTHORS
VELOCITY		Calculates ion drift velocities from line of sight measurements produced by ANAL	C.J. Burns
HEXDEC		Decodes hexadecimal files dumped from HILAT tapes	C.J. Burns
HILPLOT	GINO (graphics)	Produces summary plots of HILAT parameters from 2-minute files	C.J. Burns

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